# 2. PUGET SOUND NEARSHORE AND MARINE ECOSYSTEMS: PROCESSES, LANDSCAPES, HABITATS

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In this section, we describe (1) the relationship between ecosystem processes, landscapes and habitats in nearshore and marine environments and (2) the major regions and subdivisions of Puget Sound nearshore and marine ecosystems that we have used for salmon recovery planning. These subsections address the portion of the conceptual model highlighted in Figure 2-1.

Subsection 2.1 provides information about how nearshore and marine ecosystem processes create and maintain features that support a variety of ecosystem functions. Subsection 2.2 provides information about our approach to defining and delineating sub-basins. Subsection 2.3 provides information about the landscape classes selected for analysis within the nearshore and marine portion of the Sound. Subsection 2.4 presents a set of major uncertainties and data gaps.

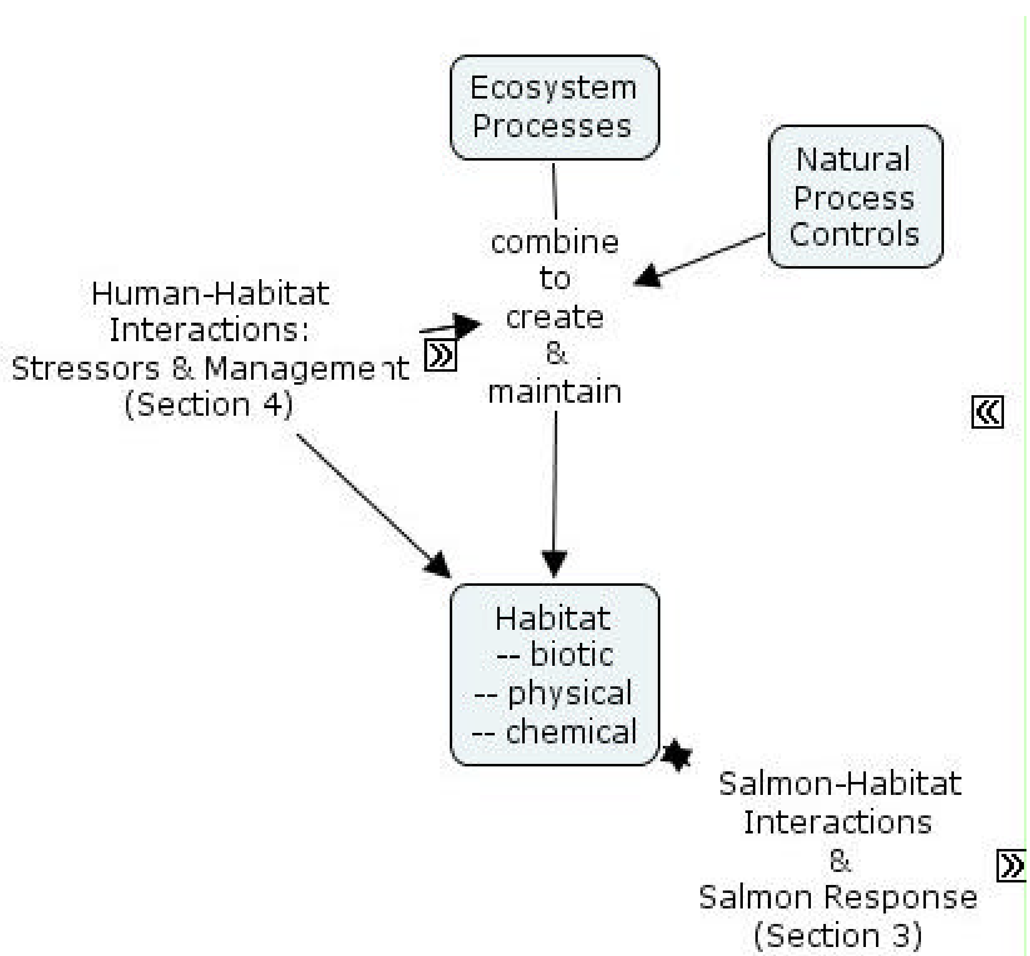


**Figure 2-1**. The ecological process-habitat portion of our conceptual model

*Physical Description*

Puget Sound and the associated inland marine waters of northwest Washington State are a large estuary complex, carved by glaciers, receiving runoff from the encircling Cascade and Olympic mountains, and connected to the Strait of Georgia and the western north Pacific Ocean through the Strait of Juan de Fuca. For this chapter, we refer to the U.S. portion of the straits of Juan de Fuca and Georgia and the marine waters landward of them as Puget Sound (see Figure 1). Using this definition, Puget Sound includes Hood Canal, the bays and passages east of Whidbey Island (aka the Whidbey Basin), Admiralty Inlet, the straits and passes around the San Juan Islands, as well as the waters Puget Sound proper including the bays and inlets of the eastern Kitsap peninsula and south Puget Sound.

Made up of a series of underwater valleys and ridges called basins and sills, Puget Sound is deep, with an average depth of 450 feet. The maximum depth of 930 feet occurs just north of Seattle. A relatively shallow sill at Admiralty Inlet separates the waters of the Strait of Juan de Fuca from the waters of Puget Sound proper. Puget Sound is surrounded by approximately 2,500 miles of shoreline, a mosaic of beaches, bluffs, bays, estuaries, mudflats and wetlands.

The waters of Puget Sound reflect a mixing of salt water from the ocean with fresh water that falls as precipitation or drains from the surrounding land. More than 10,000 streams and rivers drain into Puget Sound. Nearly 85 percent of the basin's annual surface water runoff comes from 10 rivers: the Nooksack, Skagit, Snohomish, Stillaguamish, Cedar/Lake Washington Canal, Green/Duwamish, Puyallup, Nisqually, Skokomish and Elwha.

## 2.1 <u>Key nearshore and marine ecosystem processes</u>

Giant ice sheets moving over northern North America over thousands of years created the geologic and geomorphologic template onto which Puget Sound's landscape is drawn. Oceanic and atmospheric circulation in and over the Pacific Ocean define the general character and decadal and interannual variability of climate conditions that drive the hydrologic cycle and prevailing winds in the Puget Sound basin. Predictable tides and winds, both prevailing and variable, overlay a general pattern of freshwater-driven estuarine circulation[1] to distribute low salinity water, nutrients, organic matter, and organisms through the basins, bays, and channels of Puget Sound.

These are some of the many interconnected processes that act, at different spatial scales and over different time periods, on the nearshore and marine environments of Puget Sound. Bauer and Ralph (1999) invoke hierarchy theory to suggest that "ecosystem processes and functions operating at different scales form a nested interdependent system where one level influences other levels above and below it." To further explain the relationship between process and scale, Bauer and Ralph (1999) use definitions of Naiman et al. (1992) to describe two types of controls on ecosystem processes.

[1] Freshwater, which is buoyant relative to the denser high-salinity waters of the Sound and ocean, flows ocean-ward from river mouth estuaries. By entraining some marine waters from deeper in the water column into this ocean-ward surface flow, the freshwater discharge drives a landward flow of denser oceanic waters at depth. Estuarine circulation, absent the influence of tidal and wind driven current, would be characterized by this vertical system of shallow, fresher outflow and deeper, saltier inflow.

- Ultimate controls are "factors that operate over large areas, are stable over long time periods (hundreds to thousands of years), and act to shape the overall character and attainable conditions within" a system.

- Proximate controls "are a function of ultimate factors and refer to local conditions of geology, landform and biotic processes operating over smaller areas (e.g. reach scales) and over shorter time spans (decades to years).

Principles and concepts of landscape ecology (e.g., Turner 1989) are being applied in restoration of freshwater habitats for salmonids (Roni et al. 2002) and in the evaluation of functions of nearshore systems (e.g., Hood 2002). Simenstad (2000) discussed juvenile salmon integration at large landscape scales in an assessment of the Commencement Bay aquatic ecosystem in central Puget Sound. He described three landscape elements important to salmon and salmon recovery in an estuarine landscape: 1) *patches* ("non-linear surface areas, relatively homogeneous internally…that differ in appearance from surrounding matrix in which they are imbedded," characterized by several variables and determined by a combination of several processes; can be referred to as habitats), 2) *matrix* ("surrounding area that has a different composition or structure from embedded patches; the most extensive, connected element in the landscape") and 3) *corridors* ("narrow strip of land (or water) that differs from the matrix on either side;…can also be considered a narrow and often long patch that provides a connection between two or more similar patches").

Applying the concepts of hierarchical relationships of processes and scales and landscape ecology to nearshore and marine aspects of salmon recovery we follow Simenstad's (personal communication with K. Fresh, NOAA-Fisheries) identification of three relevant scales of processes operating in Puget Sound:

- <u>Regional or large-scale processes</u> – such as plate tectonics with ensuing earthquakes and volcanic eruptions, circulation of the ocean and atmosphere with ensuing climatic events – influence all ecosystems across scales of tens to hundreds of kilometers and often produce dramatic, intense change. Climate is especially important because, to some degree, all processes are controlled by climate. Decadal scale shifts in climate are related to shifts in the abundance and distribution of fauna and prey species, and over broad regions, this can result in substantial reorganizations of ecological relationships (Francis and Hare, 1994). Regional processes can dramatically alter the physical template of Puget Sound and can not be manipulated or changed at a local scale (e.g., Puget Sound), but are nevertheless important to understand because they help control or regulate processes occurring at smaller scales.

- <u>Local or landscape-scale processes</u> are embedded within the large-scale influences and so occur at scales of kilometers or fractions thereof. Local processes include estuarine circulation of fresh- and oceanic water; sloughing, slumping, and sliding of bluffs; longshore drift of sediments; and food web interactions.

- <u>Finite or small-scale processes</u> vary at the scale of meters or fractions thereof and involve highly variable geochemical and biological processes, such as nutrient transformation in sediments and primary production by algae or eelgrass, and water column clearing and benthic transfers of nutrients and organic matter through filter feeding.

We focus especially, but not exclusively, on the landscape scale because:

- Salmon integrate with the landscape over large spatial and temporal scales as a result of a multi-year life cycle that relies on functions from freshwater and marine systems, and includes transition between and, often, considerable movement within both environments; and

- Many of the most important physicochemical and biological processes necessary to sustain functioning habitats occur at a landscape scale.

Goetz et al. (2004) hypothesize that "alterations of natural hydrologic, geomorphologic, and ecological processes impair important nearshore ecosystem structure and functions." We believe that it is reasonable to extend this hypothesis to nearshore and marine aspects of salmon recovery, particularly as the condition of landscapes and habitat features can either support or inhibit the viability of salmon and bull trout populations. Thus, our conceptual model directs us to the development of recovery hypotheses, strategies, and actions that focus on hydrologic, geomorphic, and ecological processes acting at the landscape, regional, and finite scales.

Simenstad (2000) identifies disturbance as an additional landscape-scale process. Rather than treating this as a process, we follow Bauer and Ralph (1999) in discussing natural, pulse disturbance events as a control on ecosystem processes. We discuss press disturbances (Bauer and Ralph 1999) of human origin as stressors (see Section 4.) Diverse mosaic of habitats across the landscape is created and maintained by the sporadic occurrence of events such as: extreme storms or runoff events leading to, for example, mass wasting of bluffs; and fires or volcanic events leading to, for example, changes in the recruitment of large woody debris (Simenstad 2000, Bauer and Ralph 1999).

The role of landscape-scale ecosystem processes in creating and maintaining the landscape and mosaic of nearshore and marine habitats in Puget Sound is discussed in Section 2.3. In Section 4, we discuss human stressors that impair or threaten these processes and natural controls on these processes in the Puget Sound basin.

## 2.2 Regions and sub-basins

Because of the large size and considerable heterogeneity of marine and nearshore environments in Puget Sound, we designed our evaluation of nearshore and marine landscapes and ecosystem processes to address sub-basins within the region and landscape classes and features within these sub-basins. Landscape classes and features are discussed in Section 2.3.

Our fundamental hypothesis in dividing Puget Sound into smaller pieces is that salmon utilization of different regions of Puget Sound varies according to differences in geomorphic context (e.g., landform) and oceanographic conditions. Such differences in oceanographic conditions and geomorphology help define patterns of habitat use, diet, residence time and so on, and are also important determinants of the processes that create and maintain habitat in each region.

Our subdivision of Puget Sound began with the NOAA-TRT's delineation of five geographic regions of diversity and correlated risk for Puget Sound Chinook (Figure 2-2). This delineation is one of many possible approaches to subdividing the marine waters of Puget Sound. We used the TRT approach because it (1) is specifically designed to inform recovery planning and (2) has marine boundaries generally consistent with those identified by others and already in use for ongoing programs (PSAT 2002a).

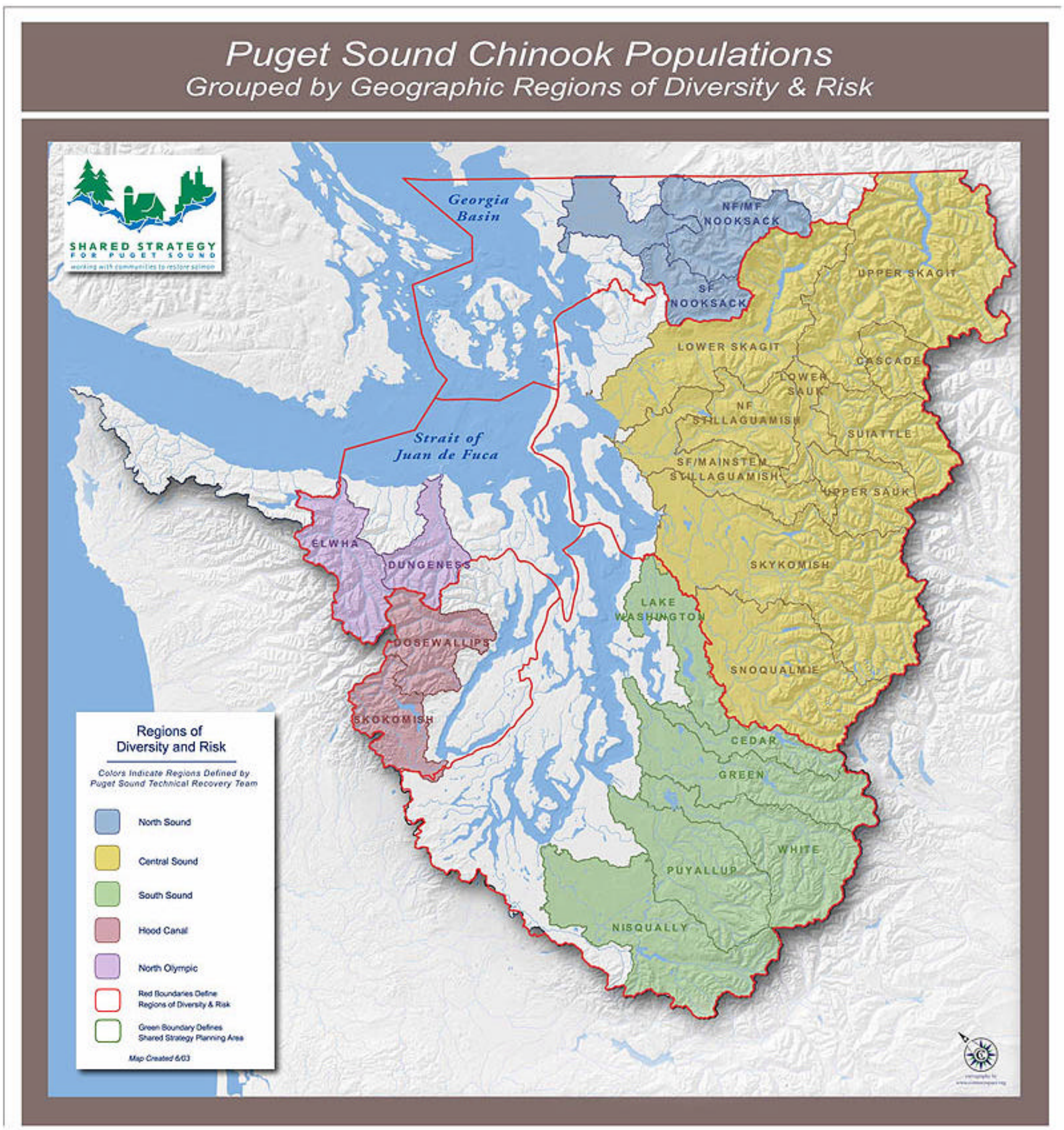


**Figure 2-2.** Five geographic regions of diversity and correlated risk for Puget Sound Chinook.[S1]

The TRT definition of five geographic regions within the Puget Sound basin reflects a synthesis of prior delineations of:

- marine basins (per Ebbesmeyer et al. 1984 cited in PSAT 2002a),
- terrestrial ecoregions (Omernik & Bailey 1997), and
- genetic diversity units of Puget Sound Chinook salmon stocks (citation?).

We considered assessing and evaluating the marine areas of each of these regions but decided instead to further subdivide some of these areas to describe and address more homogeneous marine basins. We accomplished this by adapting Ebbesmeyer et al. (1984) and PSAMP (PSAT 2002a) delineations of marine basins, which follow oceanographic conditions, amount of freshwater inflow and other indicators. This approach yields a system of 11 marine sub-basins (Figure 2-3). [1]

Note that we have not included the western portion of the Strait of Juan de Fuca in our delineations. This is an artifact of our decision to simply subdivide, or use whole, the available TRT-defined regions. We understand that our treatment of the Strait of Juan de Fuca should be revised to include (1) the region out to Neah Bay/Cape Flattery and (2) sub-basin boundaries that better follow oceanographic conditions on the Strait. We also understand that the TRT regions may be re-defined to address inclusion of the western Strait.

Based on our definition of nearshore environments (e.g., depths of less than 20 m below MLLW), Puget Sound contains more than 641 square miles of nearshore and more than 1,817 square miles of deeper marine environments. Nearshore and deep water habitats are not evenly distributed among the 11 sub-basins of Puget Sound (Figure 2-3). The Whidbey sub-basin contains the greatest quantity of area classified as nearshore (121 square miles), with 50% of this sub-basin's total area classified as nearshore. Eighty-one percent of the Padilla and Samish Bay sub-basin's total area of 66 square miles is classified as nearshore. Conversely, only 11% of the Eastern Strait of Juan de Fuca sub-basin's total area of 74 square miles is classified as nearshore.

## 2.3 Landscape Classes

To describe the key nearshore and marine subsystems within Puget Sound's marine sub-basins, we have defined landscape classes that provide a foundation for describing how ecosystem processes form and affect the landscape of Puget Sound and for presenting information in Sections 3, 4, and 6. As used in this chapter, a *landscape class* is a type of environment within a sub-basin that is influenced by a distinct set of ecosystem processes. These landscape classes

[1] In order to analyze the attributes of each of these units (e.g., water quality), it is necessary to define or draw boundary lines between the 11 marine sub-basins we have defined (as shown in Figure 2-4). We suggest that these boundaries should be viewed as "fuzzy" lines because the processes used to delineate the sub-basins do not begin and end at discrete points. Thus, the precise lines shown on Figure 2-4 are less important than their general location and rationale for the selection of the sub-basins as discrete units for evaluation.

generally reflect processes that operate at the spatial scale of miles to tens of miles and the time scale of decades and centuries.

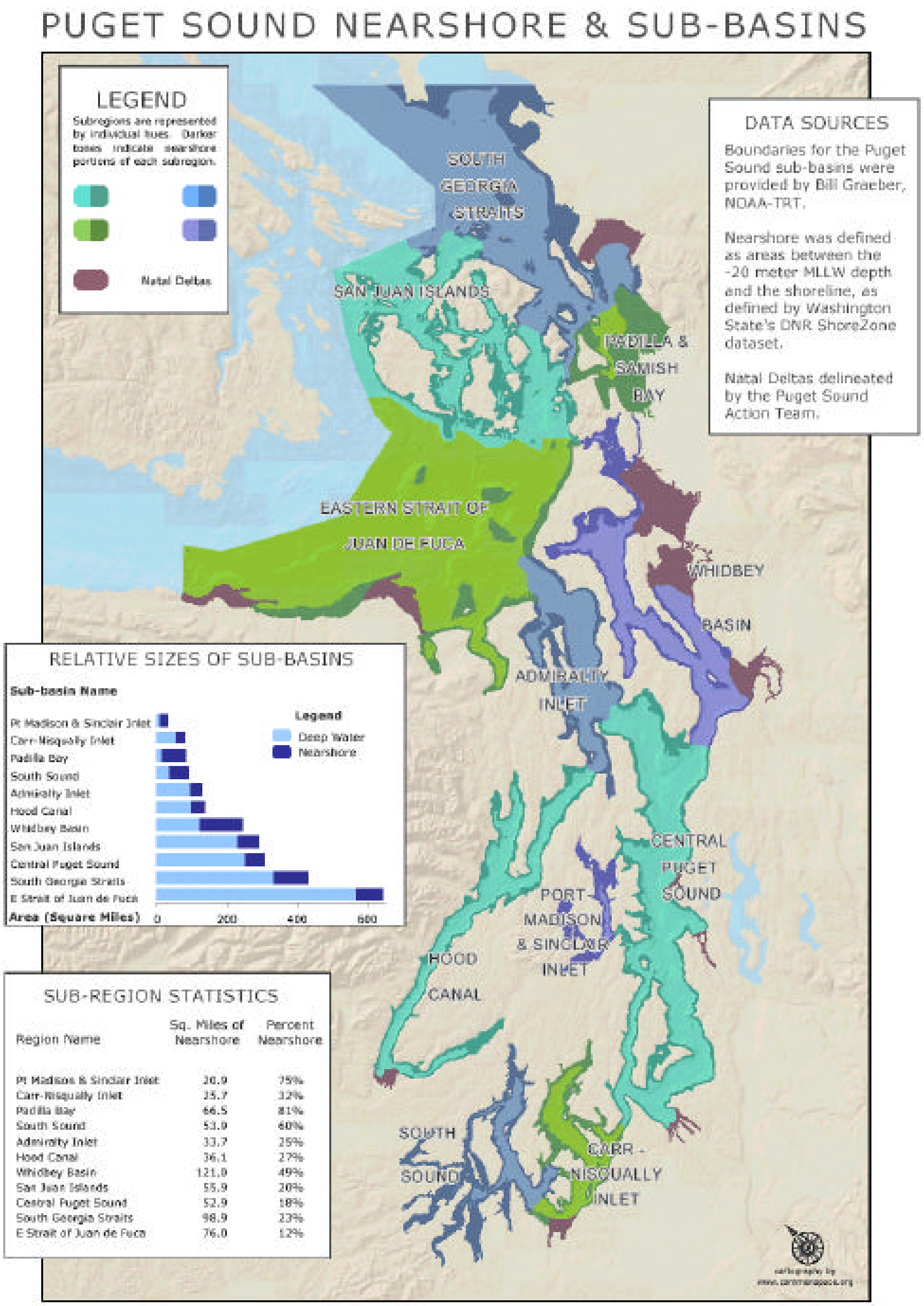


Figure 2-3. **Eleven marine sub-basins and nearshore portions of Puget Sound.** **[S2]**

Following some of the preliminary decisions from the PSNERP Nearshore Science Team about a habitat typology for nearshore environments in Puget Sound (Shipman et al., in prep.), we describe the nearshore and marine environments of each sub-basin according to four broad landscape classes, including three classes of nearshore environments and one class that captures the deeper waters of a sub-basin:

1. Estuaries
2. Bays
3. Beaches
4. Marine Waters

Each of these landscape classes includes a number of embedded features and smaller scale habitat types, such as lagoons, mudflats, bluffs, spits, eelgrass beds, blind tidal channels, and the water column. Various types of features and habitat types can occur in more than one landscape class. For example, an estuary and a lagoon feature of a beach may each contain emergent marsh and mudflats.

The following paragraphs provide a brief description of each of the landscape classes and examples of occurrences of these classes in Puget Sound. In addition, key features, habitat types, and ecosystem process that characterize each of the landscape classes are discussed.

2.3.1 Estuaries. Within the large estuarine complex of Puget Sound, there are a number of larger river estuaries (e.g., Skagit, Nisqually) and many additional smaller estuaries (Gorst Creek, Ennis Creek). For purposes of this chapter, we define an estuary as the area at the mouth of a river or stream dominated by processes related to the discharge of fresh water. We describe the spatial extent of an estuary as the area from the head of tidal influence seaward to the point where fluvial influences no longer dominate. Table 2-1 lists 23 of the largest estuaries in Puget Sound. The discharges of many smaller rivers and streams also form estuaries where they enter Puget Sound. Key estuaries in Puget Sound are depicted in sub-basin maps in Section 6.

Estuaries occur in a variety of sizes, shapes, and geomorphic settings. Most estuaries include some mix of shallow, dendritic, blind channel networks; backwater, distributary sloughs and small channels; large, main channels with fringing vegetation; and mud/sand flats.

For example, a freshwater drainage (watershed) that extends three to five miles inland that has been carrying sediment toward Puget Sound for several hundred years is likely to create a small estuary. This estuary will likely be evident on the landscape as a network of distributary channels over a deltaic fan.

Processes operating at multiple scales significantly influence features of the habitats within any estuary but the location along the estuarine gradient is especially important (Simenstad 2000). Salinity regimes are a primary determinant of vegetation, invertebrate, and fish community composition, are very dynamic and depend on a variety of factors including tide, riverine inputs, and bathymetry.

Cowardin et al. (1979) developed a system of wetland classification that is often used to describe estuarine habitats. This scheme identifies three discrete habitat zones within estuaries:

**Table 2-1. Major estuaries of Puget Sound[1]**

| Estuary, named for river or stream entering Puget Sound | Drains land of water resource inventory area (WRIA): | Enters Puget Sound at: | Average annual discharge in cubic feet per second (cfs) |
|---|---|---|---|
| Nooksack | 1 | Bellingham Bay | 3810 |
| Skagit | 3 and 4 | Skagit Bay | 16300 |
| Stillaguamish | 5 | Port Susan | 2010 |
| Snohomish | 7 | Possession Sound | 9480 |
| Lake Washington Ship Canal* | 8 | Salmon Bay/Main Basin | |
| Duwamish | 9 | Elliott Bay | 1500 |
| Puyallup | 10 | Commencement Bay | 3330 |
| Chambers Creek | 12 | Nisqually Reach | 113 |
| Nisqually | 11 | Nisqually Reach | 1860 |
| Deschutes | 13 | Budd Inlet | 404 |
| Kennedy Creek | Each drains a portion of 14 | Totten Inlet | 61 |
| Goldsborough Creek | | Hammersley Inlet | 107 |
| Union | Each drains a portion of 15 | Lynch Cove (Hood Canal) | 51 |
| Dewatto Creek | | Hood Canal | 71 |
| Skokomish | Each drains a portion of 16 | Great Bend of Hood Canal | 1190 |
| Dosewallips | | W. shore of Hood Canal | 450 |
| Duckabush | | W. shore of Hood Canal | 428 |
| Hamma Hamma | | W. shore of Hood Canal | 423 |
| Big Quilcene | Each drains a portion of 17 | Dabob Bay of Hood Canal | 143 |
| Little Quilcene | | Dabob Bay of Hood Canal | 52 |
| Dungeness | Each drains a portion of 18 | Dungeness Bay | 380 |
| Morse Creek | | Strait of Juan de Fuca | 135 |
| Elwha | | Strait of Juan de Fuca | 1520 |

* *This is not a location of significant natural drainage; the landscape and habitats at the mouth of the Ship Canal at Salmon Bay do not reflect the influence of fluvial processes as evident at other estuary locations.*

1. Tidal, riverine forests and wetlands.
2. Emergent, forested transition (scrub shrub).
3. Estuarine, emergent marshes.
4. Estuarine (delta) mudflats or tide flats.

These habitat zones are primarily distinguished by location along the estuarine gradient, which defines salinity regime, patterns of tidal inundation, and thus vegetation type. The tidal riverine zone is located in the upper portion of the estuary, the emergent, forested transition habitat zone occurs in the middle part of the estuary, and the emergent marsh area occurs near the outer delta. The historic reconstruction of major estuaries in Puget Sound by Collins et al. (2003) has shown that each estuary possessed its own unique proportion of each habitat zone and each has been significantly altered in recent time.

[1] Includes all river and stream discharges listed as greater than 50 cubic foot per second annual average discharge (Sinclair & Pitz 1999).

The movement of water within the estuary (hydrologic processes) has a fundamental influence on many of the functions of estuary habitats. Within estuaries, water erodes and deposits sediments, acquires and transports nutrients and organic matter, and transports fish and prey items. For example, organic matter supporting food webs can be transported from upstream areas and moved around within the estuary. In addition, the shape and complexity of the channel network in any part of the estuary depends upon processes involving water movement, geological and topographical features (e.g., slope, depth, connections to other habitats, size of the system, and landform), which in turn depend upon location within the estuary. Within estuaries, water movement occurs as a result of river flows, tides, and waves. The acquisition and transport of sediments by water within estuaries helps shape deltaic habitats. An important source of sediments in estuaries is upstream of the estuary from the watershed.

As in freshwater reaches of rivers, deltaic channel structure is forced by fluvial processes operating on large woody debris and sediment (Collins et al. 2003). Nearshore processes also operate on large woody debris to similarly create fine scale habitat features, such as pockets and bars, in estuaries (Gallagher 1979).[S3]

2.3.2 Bays. While geographers have assigned the name "bay" to all kinds of semi-enclosed waterbodies, we define this landscape class as shoreline reaches characterized by limited wave action, often resulting from limited exposure to winds. Tidal flows and circulation are the dominant processes that create and maintain habitats in bays. As a result, bays are typically areas of some shallow water and low velocity, where tidal processes are especially important to delivery and movement of fine sediments.

Bays are subject to less wave and current energy than the open shorelines of beaches (discussed below) and less influenced by freshwater input than estuaries. If a bay is relatively large (e.g., Commencement Bay) and includes some areas of greater exposure to wind waves, beaches (the third landscape class) could be nested within it. Freshwater input and influence in bays varies, but most bays in Puget Sound receive freshwater inputs from estuaries and, therefore, have some areas of lower salinities.

Examples of bays in Puget Sound include Discovery Bay, Commencement Bay, Budd Inlet, and Hammersley Inlet. The protected shorelines of bays include geographic regions of Puget Sound such as Camano Island and the east shore of Whidbey Island.

Types of nearshore habitats occurring in bays may include:

- Non-vegetated mud flats (gentle slope),
- Non-vegetated steep slopes,
- Eelgrass meadows,
- Fringing eelgrass,
- Fringing kelp,
- Rock – kelp (e.g., interior San Juan Islands),
- Marshes
- Riparian[S4]

Bay shorelines, because of the limited wave action, often contain marine riparian zones or shorelines with overhanging vegetation. These marine riparian zones are important transition areas between the terrestrial, freshwater, and marine ecosystems, contributing to the health of the nearshore ecosystem and providing functions such as protection of water quality, shade, bank stability, and input of nutrients and large woody debris (Williams *et al*. 2001). For example, shading can be important for managing water temperatures in tidal channels, streams or seeps; vegetation and intact soils of riparian areas can be effective as sediment and pollution controlling mechanisms; riparian areas can be a source of organic matter and provide bank stabilization; and contribute habitat structure by way of large woody debris (LWD) (Williams *et al*. 2001). Functioning riparian zones can also be found along estuaries and beaches.

2.3.3 <u>Beaches</u>. This landscape class is defined or characterized as shorelines where the dominant process is littoral drift, which moves sediment by wave action. Beaches occur over large geographic regions of Puget Sound such as the east shore of the Sound from Edmonds south to Dupont, and the west side of Whidbey Island. Beaches are subject to greater wave and current energy than the other landscape classes largely because of the relatively greater distances over which wind and waves can travel (fetch). Several features can be embedded within beaches, including stream mouths, spits, bars, lagoons, rocky headlands, etc.

Drift cells are the process-based organizing unit over which (most) beaches operate. In general, the net drift of sediments along marine shorelines transports sediment from eroding areas to depositional areas along a mappable length of shoreline known as a drift cell. This fundamental unit of longshore sediment transport where waves and currents cause localized erosion, carry sediments for some distance down the beach in a predictable direction and deposit them when the wave energy is insufficient to keep the particles suspended. Sediment transport within shoreline drift cells determines the ultimate size, shape and configuration of soft sediment depositional features along the shoreline like beaches, spits, berms and mudflats. Larger sediment particles like gravel, cobble, boulders and large woody debris that wash from eroding bluffs travel the shortest distances because gravity exceeds the force of suspension. Woody debris that dislodges from the beach during high tides and smaller grain sizes like sand and silt, travel further along the drift cell or remain suspended to export offshore. These traveling sediments interact with freshwater outflows from streams and glacially carved curves of the shoreline and can create various landscape features. Figure 2-4 presents a graphic of a “typical” drift cell with erosional, transport and depositional sections.

This focus of littoral drift as the main process creating and affecting beaches leads to the identification of two types of features: 1) <u>barrier</u> beaches, which are generally depositional in nature, and 2) <u>bluff-backed</u> beaches, which are erosional regions.

The dominant habitat features in beach landscape classes include:

- Non-vegetated sand flats (gentle slope),
- Non-vegetated beach slopes of cobble, gravel, sand, and mixed substrates,
- Spits,
- Lagoons,
- Marshes,
- Fringing eelgrass (e.g., Hood Canal),

- Fringing kelp,
- Kelp beds – wave cut platform (e.g., Strait of Juan de Fuca),
- Rock – kelp (e.g., San Juan Islands).
- Backshore berms
- Vegetated bluffs[S5]

Many of these habitat features depend on a continual supply of sediment and wood moving through beach systems.

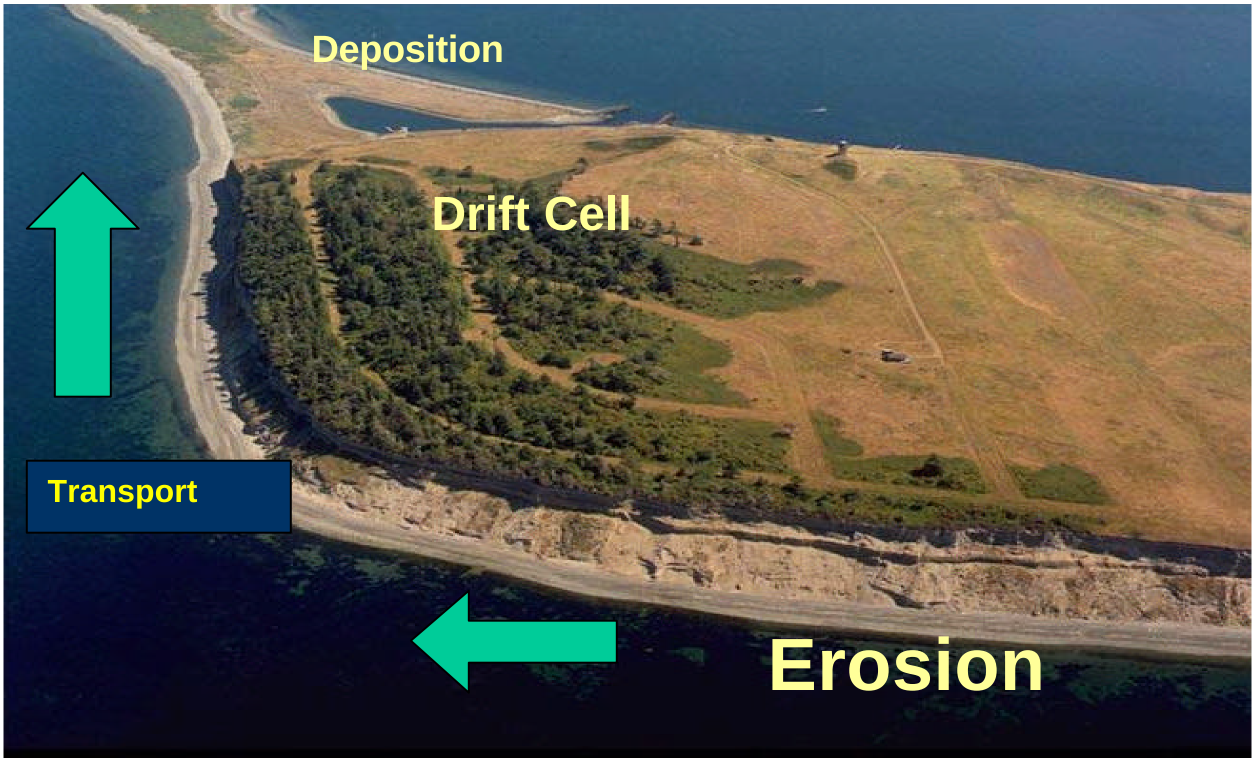


**Figure 2-4.** A "typical" drift cell in Puget Sound.

2.3.4 Marine Waters. The waters of Puget Sound include both neritic, or nearshore, and offshore waters. Using our definition of nearshore, we include neritic waters in the landscape classes discussed above. We have not, however, discussed the water column of these classes in the previous sections and so address them here.

The marine waters of each Puget Sound sub-basin connect either through other sub-basins or directly to the North Pacific Ocean (see Figure 2-3). The primary processes affecting the marine waters of Puget Sound include:

- circulation to deliver and mix water masses (e.g., from the Pacific ocean, other sub-basins, or river and stream discharges) with their characteristic temperature, salinity, nutrient load, and oxygen content;

- primary production of organic matter by phytoplankton and secondary production from resident pools or imported detritus; and

- trophic transfer of energy among organisms.

Defined (in part) by the interplay of these processes, habitat types within marine waters include the sea surface microlayer, surface water (photic zone), near-bottom waters, and soft or hard substrates of various types.

We have little information about the sea surface microlayer but expect that it is very important biologically (e.g., with concentrations of eggs and larvae of marine organism).

The controls on the processes of circulation and primary production include climate-ocean influences, the spatial arrangements of Puget Sound inlets and passages, and the delivery of nutrients. Estuarine circulation (as introduced earlier in Section 2) keeps surface waters somewhat distinct from deeper waters. Since surface waters receive sufficient sunlight to support photosynthesis, nutrients delivered to these waters (e.g., from freshwater discharges or mixing with deeper oceanic waters) can be consumed relatively quickly to fuel the growth of phytoplankton. Where the water column is fairly stable, phytoplankton can bloom to the extent that light and nutrient conditions allow. Primary production in many waters of Puget Sound is limited by the availability of nitrogen and these waters are susceptible to water quality impairments related to delivery of excess nutrients from pollution or oceanic events (PSAT 2002a).

Major ocean-climate effects on the Pacific Northwest and on Puget Sound marine water conditions relate to decadal time scale oscillations (PDO for Pacific decadal oscillation) between a phase of relatively warm and dry years and a phase of relatively cool and wet years. A shorter term El Nino-Southern Oscillation (ENSO) climate cycle interacts with the PDO and also affects the region with recurrent annual-scale shifts to El Nino (warm) or La Nina (cold) conditions in the Pacific Ocean. These combined PDO and ENSO climate phase shifts affect ocean temperature and salinity and this region's precipitation and air temperature. These factors in turn affect salinity, temperature, and primary productivity of Puget Sound marine waters by affecting the amount of solar radiation, rates of evaporation, patterns of runoff, and upwelling of ocean waters.

The (neritic) waters of the nearshore landscape classes (discussed above) receive particulate and dissolved nutrient inputs from land, rivers and streams, from fluxes out of sediment deposits, and from oceanic sources (e.g., through upwelling processes and estuarine circulation). Deeper marine waters are, in turn, influenced by ocean conditions and by mixing, especially at the surface, with neritic waters.

### 2.4 Major uncertainties & data gaps

Key uncertainties and data gaps related to the process that develop and maintain nearshore and marine ecosystems include:

- The role marine riparian zones play in contributing organic matter, nutrients, and food items across the terrestrial-nearshore interface;

- Historic distribution of habitats, and the processes that created and maintained them, the Puget Sound landscape;

- The functional state of fringing eelgrass beds and eelgrass meadows in various sub-basins of Puget Sound.

- Improved understanding and descriptions of the key ecosystem processes in bays (benthic-pelagic transfers of organic matter and nutrients, nutrient cycling moderated by filtering organisms and tidal circulation.

- Further evaluation of the linkages between climate variability, global climate change, and population dynamics.